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FINAL TECHNICAL REPORT FOR AFOSR GRANT

INTEGRATED EXPERIMENTAL SYSTEM FOR TURBULENT FLOW - ELASTIC SURFACE INTERACTIONS

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1. ABSTRACT

The overall goal of this investigation is to design, acquire and implement components that form an integrated system for detecting the instantaneous structure of unsteady and turbulent flows, in conjunction with elastic motions of an adjacent surface. Central to this technique is use of a high-powered Argon-ion laser that scans through space at time scales orders of magnitude smaller than the characteristic time scale of the flow. This approach provides the basis for two-dimensional and three-dimensional scans of complex flows. The instantaneous deflection of the surface is to be acquired by a video zoom technique or, alternately, a speckle technique. Quantitative evaluation of the images acquired using this approach involve the use of critical point theory, in conjunction with flow topological techniques and pressure source representations of the unsteady flow. These techniques require the instantaneous, global features of the flow.

2. EXPERIMENTAL SYSTEMS

A new high-powered Argon continuous wave laser (25 watt rating) has been acquired and interfaced with beam conditioning optics. This optics arrangement combines several types of lenses, including a singlet, in order to provide a sufficiently narrow waist of the beam for impingement upon the rotating multi-faceted mirror, which provides the scanning, and a minimal diameter of the beam at the cross-section of the plane of the flow.

Scanning of the laser beam is achieved by one of two techniques. The first, employing relatively high speeds, involves a multi-faceted rotating mirror. It provides sweeping frequencies up to 2,000 cycles/sec. For lower speed flows, an oscillating, galvanometer-driven mirror is used to provide scan frequencies up to 100 cycles/sec. The three-dimensional scanning version of this system has been designed, and the main housing manufactured. In essence, it employs two orthogonally-oriented rotating mirrors, each having 72 facets, which will provide rapid scanning of the laser beam through three-dimensional space.

Images are recorded using two basic types of film-based systems. The first involves a motor-driven 35 mm camera, having a framing rate of five to ten frames per second. This second is a high-speed framing camera, with a framing rate of up to sixty-five frames per

second. Both of these cameras are synchronized with the laboratory computer system, in order to provide coordination between the camera shutter opening and defined motion of the body or of the flow past a body. This film-based approach has a resolution substantially exceeding that of traditional video systems. High resolution film has an equivalent resolution of 350 pixels/mm; these images are digitized at an effective resolution of 125 pixels/mm.

Video-based image acquisition will involve a newly-released high resolution video camera made by Kodak (model ES.1). In conjunction with an imaging technology incorporated framegrabber, having an effective transfer rate of 90 Megaherz. These images will be downloaded to the ram of the host microcomputer. Since the date is already in digital form, the process of image digitizing will not be necessary. Interrogation of the stored image patterns, to determine the velocity fields will also be done on the host computer. This video system will be interfaced with the rotating mirror. Units are described in the foregoing using a synchronizer developed by TSI, Inc. To effect this interfacing, it will be necessary to employ a Pockels cell system to limit the number of laser beam sweeps for the second range of exposure. By using a cross-correlation between successive video frames, it will be possible to optimize the resolution of the video system, which is rated at approximately 10^6 pixels.

Determination of the surface deflection will be accomplished using one of two techniques. The first involves a highly magnified image of the local region of the surface, which will be tracked using the film-based camera or the video systems described in the foregoing. These local deflections of the surface can be synchronized with the instantaneous, adjacent flow patterns, thereby providing a quantitative relationship between the surface deformation and the predominant features of the flow. This technique has already been implemented for the film-based systems. The second approach involves a speckle technique, for which the video system is ideally suited.

3. ACCOMPLISHMENTS/NEW FINDINGS: POST-PROCESSING OF IMAGES.

The central goal of this instrumentation grant was to relate the underlying physics of the flow to loading and deflection of the adjacent surface. In doing so, several theoretical approaches have been investigated and implemented during the past two years.

Acquisition of instantaneous velocity fields allows determination of the corresponding streamline patterns in an arbitrary frame of reference, thereby allowing definition of the critical points of the flow based on topological techniques. These critical points involve, for example, saddle points, stable and unstable foci, nodal lines, etc. In a number of the investigations cited in the List of References, definition of how these critical points evolve with time has been instrumental in understanding the coupling between surface (body) motion in the surrounding flow.

The instantaneous velocity field will also lead to calculation of pressure source terms, which are important for understanding not only the loading of an adjacent surface, but also the radiated sound from the surface. These source terms have been calculated, and contours of constant pressure sources have been related to corresponding instantaneous

contours of constant vorticity, in order to determine the manner in which the development of the vorticity field gives rise to pronounced pressure sources.

Finally, knowledge of the instantaneous velocity field allows direct calculation of the vorticity. The manner in which this vorticity field evolves with time is central to determining the relation between loading of an oscillating body and the flowfield surrounding it. Two different approaches have been applied. The first involves use of moments of vorticity, in conjunction with the Lighthill concept. The time rate of change of these moments of vorticity is directly related to the instantaneous lift and drag on the body. A second approach, which must be invoked for the case where the vorticity extends well beyond the region of interest of the body, involves a momentum balance, undertaken with aid of the Reynolds Transport Theorem. This approach has proved successful for an oscillating body, provided the reference frame transformations are properly accounted for.

4. PERSONNEL SUPPORTED

Not applicable - this grant was an instrumentation grant with no support provided for personnel.

5. PUBLICATIONS (1995-1997 only)

The experimental systems defined in the foregoing were applied for a broad range of experimental investigations supported by Air Force Office of Scientific Research, the Office of Naval Research, and the National Science Foundation. A summary of the experimental findings is given in each of the publications which benefit from this instrumentation grant.

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